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Pediatric Cardiology

Myocardial Bridging Does Not Predict Sudden Death in Children With Hypertrophic Cardiomyopathy but Is Associated With More Severe Cardiac Disease

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OBJECTIVES We sought to examine the association between systolic compression of sections of epicardial coronary vessels (myocardial bridging) with myocardial perfusion abnormalities and clinical outcome in children with hypertrophic cardiomyopathy (HCM).

BACKGROUND It has recently been suggested that myocardial bridging is an important cause of myocardial ischemia and sudden death in children with HCM.

METHODS Angiograms from 57 children with HCM were reviewed for the presence of bridging (50% or more maximum systolic arterial compression). QT interval indices, echocardiographic and cardiac catheterization findings, treadmill exercise tests, exercise thallium scintigraphy, Holter monitoring and electrophysiologic study findings were compared in children with and without bridging. The findings were also related to the presence or absence of compression of septal branches of the left anterior descending artery (LAD).

RESULTS Bridging was present in 23 (40%) of the children. Multiple coronary arteries were involved in four children. Bridging involved the LAD in 16 of 28 (57%) affected vessels. Myocardial perfusion abnormalities were present in 14 of 30 (47%) children without bridging and in 17 of 22 (94%) children with bridging, $p = 0.002$. However, bridging was associated with more severe septal hypertrophy (19 ± 8 mm vs. 28 ± 8 mm, $p < 0.001$), a higher septum:posterior wall thickness ratio (2.7 ± 1.2 vs. 1.8 ± 0.9, $p < 0.001$), and higher left ventricle (LV) outflow gradient (45 ± 37 mm Hg vs. 16 ± 28 mm Hg, $p = 0.002$). Compression of septal LAD branches was present in 37 (65%) of the children and was significantly associated with bridging, severity of LV hypertrophy and outflow obstruction. Multivariate analysis demonstrated that LV septal thickness and septal branch compression, and not bridging, were independent predictors of thallium perfusion abnormalities. There was a 90% power at 5% significance to detect an effect of bridging on thallium abnormalities at an odds ratio of 3. Bridging was also not associated with significantly greater symptoms, increased QT and QTc intervals and QTc dispersion, ventricular tachycardia on Holter or induced at EP study, or a worse prognosis.

CONCLUSIONS Bridging and compression of septal branches of the LAD are common in HCM children and are related to magnitude of LV hypertrophy. Left ventricular hypertrophy and compression of intramyocardial branches of the epicardial coronary arteries may contribute to myocardial perfusion abnormalities. Our findings suggest that bridging does not result in myocardial ischemia and may not cause arrhythmias or sudden death in HCM children. (J Am Coll Cardiol 2000;36:2270–8) © 2000 by the American College of Cardiology

Chest pain and myocardial ischemia are common in hypertrophic cardiomyopathy (HCM). About two-thirds of adult patients have regional myocardial perfusion abnormalities as demonstrated by exercise thallium-201 scintigraphy and positron emission tomography studies (1,2). Further evidence for myocardial ischemia has been provided by stress-induced anaerobic metabolism with reduced myocardial lactate consumption or lactate production in patients with a history of chest pain (1). Children with HCM are at higher risk for sudden death than adult patients, and exercise thallium myocardial perfusion abnormalities occur more frequently in children who present with syncope or cardiac arrest (3).

Several mechanisms have been proposed to explain myocardial ischemia in HCM. These include increased metabolic demand (4,5), dysfunction and paucity of the coronary microvasculature (5–8), elevated left ventricle (LV) diastolic pressure reduced vasodilator reserve (9,10), bridging of epicardial coronary arteries (1,11–13) and compression of septal branches of the left anterior descending artery (LAD) (4,14–17).

The significance of compression of sections of epicardial coronary vessels has been controversial. In a recent communication, Yetman et al. (13) report that bridging is an important cause of angina and myocardial ischemia, is associated with greater dispersion of the QT interval and is a significant risk factor for ventricular arrhythmias and sudden death in children

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Abbreviations and Acronyms

ECG = electrocardiogram
EP = electrophysiologic study
HCM = hypertrophic cardiomyopathy
LAD = left anterior descending artery
LV = left ventricle
QT = QT interval
QTc = corrected QT interval
VT = ventricular tachycardia

with HCM. Given the potential therapeutic implications of these observations, we have reviewed the prevalence and clinical correlates of bridging in HCM children evaluated at the National Institutes of Health.

METHODS

Patients. The study comprised children with HCM who underwent coronary angiography at the National Institutes of Health between January 1989 and April 1999 and included children whose records were assessed retrospectively. All children underwent M-mode and 2D echocardiography and HCM was defined as a hypertrophied, nondilated LV in the absence of another cause for the increased cardiac mass. Studies were performed after >5 half-lives off all cardiac medications.

Measurements. HEMODYNAMIC STUDIES. Cardiac catheterization was performed using intravenous sedation. Right heart pressures and cardiac output were measured with a thermodilution Swan–Ganz catheter. Left ventricle outflow pressure gradient was recorded from the side-arm of a femoral artery sheath, a 5F or 6F end-hole pigtail catheter placed in the LV and also by careful withdrawal of the catheter from LV apex to ascending aorta. Significant obstruction was defined as a subvalvular gradient of >30 mm Hg at rest or >50 mm Hg following provocation.

ANGIOGRAPHIC ASSESSMENT OF BRIDGING. Selective coronary angiography was performed using standard Judkins catheter technique. Cineangiographic films were reviewed independently by two observers, one of whom was blinded to clinical histories. All coronary segments showing evidence of bridging were assessed quantitatively. A 35 mm cineprojector incorporating a digital video camera was used to capture images of each bridged artery. Angiographic boundaries were detected automatically by the analysis software and manual corrections made when necessary. Absolute arterial dimensions (mm) were measured using the coronary artery catheter as reference. The following were estimated: length of bridged segment and severity of bridging [(systolic diameter of the artery just distal to bridging minus systolic diameter of the bridged segment) ÷ systolic diameter of the artery just distal to bridging × 100]. Coronary bridging was defined as a maximum systolic compression ≥50% (13).

SYSTOLIC COMPRESSION OF SEPTAL BRANCHES OF THE LAD. Septal perforator compression was defined as the transient occlusion of septal branches of the LAD during systole and was determined to be either present or absent by two independent observers.

EXERCISE DURATION, HEART RATE AND BLOOD PRESSURE RESPONSES TO EXERCISE. Treadmill exercise tests were performed using the Bruce protocol. Exercise duration, heart rate and blood pressure responses were recorded. An abnormal exercise blood pressure was defined as <20 mm Hg increase in peak sphygmomanometer systolic pressure compared with resting value (18).

MYOCARDIAL ISCHEMIA. Exercise thallium scintigraphy was performed following an overnight fast by previously described methods (3). At peak exercise, up to 2 mCi of thallium (dose determined by patient weight) was administered intravenously and the patient exercised for an additional 45 to 60 s, with thallium images obtained within 10 min after exercise. Repeat images were acquired approximately 3 to 4 h later following administration of up to 1 mCi of thallium. Horizontal long axis, vertical long axis, and short axis tomograms were reconstructed and analyzed qualitatively in the anterior, apical, inferior, septal and lateral regions. Stress and reinjection images were normalized to the region with the maximum myocardial activity on the stress images and each region was assigned as abnormal or normal. A region of reduced thallium uptake was determined to be abnormal but reversible if it normalized on reinjection images, and to be abnormal and irreversible if it persisted. The presence or absence of apparent cavity dilation was also determined.

ARRHYTHMIAS. Holter recordings obtained nearest the time of angiography were analyzed for the presence or absence of ventricular tachycardia (VT), defined as >3 beats duration. The QT and QTc intervals were measured from the 12-lead electrocardiogram (ECG) by a physician blinded to the clinical findings. QTc dispersion was defined as the difference between the longest and shortest QTc intervals measured on all 12-lead ECG leads. Electrophysiologic (EP) studies were performed at the time of the cardiac catheterization in 36 of the children using previously described methods (19).

Statistical analysis. Patient data are presented as mean ± 1 SD. Two-sample data were compared by Student *t* test. Cardiac survival rates for patients with and without bridging were determined by the Kaplan–Meier estimates and compared with the logrank test. Cardiac events were defined as sudden death or resuscitated cardiac arrest. Multivariate logistic regression analysis was used to determine the independent contributions of LV wall thickness, LV outflow obstruction, septal compression and bridging to presence of thallium perfusion abnormalities. The power of the study to detect a contribution of bridging to thallium abnormalities was calculated on the binomial model with the logit link with and without adjustment for confounding effects of the other vari-

Table 1. Clinical Findings in the HCM Children: Prevalence of Risk Factors

Cardiorespiratory arrest, syncope and/or presyncope	35 (61%)
Family history of ≥2 premature sudden death	12 (21%)
Myocardial ischemia	31 (54%)
VT during ambulatory Holter monitoring	14 (25%)
Genetic abnormality associated with a poor prognosis	4 (6%)
Severe LV hypertrophy (LV wall thickness ≥30 mm)	12 (21%)
Flat* or hypotensive BP response to baseline exercise	26 (46%)
≥1 clinical features associated with sudden death	53 (93%)

*<20 mm Hg increase in systolic arterial blood pressure (BP).

ables (20). A p value < 0.05 was considered statistically significant.

RESULTS

Characteristics of the study population. From a total of 163 children admitted for assessment during this 10-year period, 57 (35%) had selective coronary angiograms of sufficient quality for quantitative analysis. Of these, 35 (61%) were catheterized before the identification of coronary bridging as a potential determinant of outcome and their angiograms and case histories were reviewed retrospectively. Indications for catheterization included the characterization of LV outflow gradient, the assessment of children considered to be at high risk for sudden death, and for symptoms such as chest pain, dyspnea and syncope. The 22 children assessed after this time were a consecutive series and had similar clinical features. Henceforth, no distinction is made between these groups. There was a high prevalence of risk factors associated with sudden death (Table 1).

Prevalence, severity, and distribution of bridging. Myocardial bridging is illustrated in Figure 1. A total of 28 bridges were present in 23 (40%) of the children. Multiple bridging sites were identified in 4 (7%) of the 57 children: 2 coronary segments in 3 patients, and 3 segments in 1 patient. Bridging was located at mid-LAD in 13 (46%), proximal LAD in 1 (4%), distal LAD in 2 (7%), a diagonal branch in 5 (18%), an obtuse marginal branch in 4 (14%), and the posterior descending branch of the right coronary artery in 3 (11%) of all 28 bridges. The mean length of the compressed coronary segment was 15 ± 7 mm, range 6 to 39 mm, with a mean systolic narrowing of 76 ± 18%. The severity of maximum compression was between 50% and 75% in 15 (54%) and 75% and 100% in 13 (46%) of the bridges. Complete systolic occlusion of the coronary lumen was seen in 8 (29%) of the bridges.

The relation of bridging to clinical findings. The clinical correlates of bridging are shown in Tables 2 and 3. The ages at diagnosis of HCM and cardiac catheterization were similar in the children with and without bridging. Clinical presentation (chest pain and symptoms of impaired consciousness, including cardiac arrest) was similar in the two groups.

ECHOCARDIOGRAPHY. LV wall thickness at proximal interventricular septum was significantly greater in the children with bridging; the mean septal thickness in children

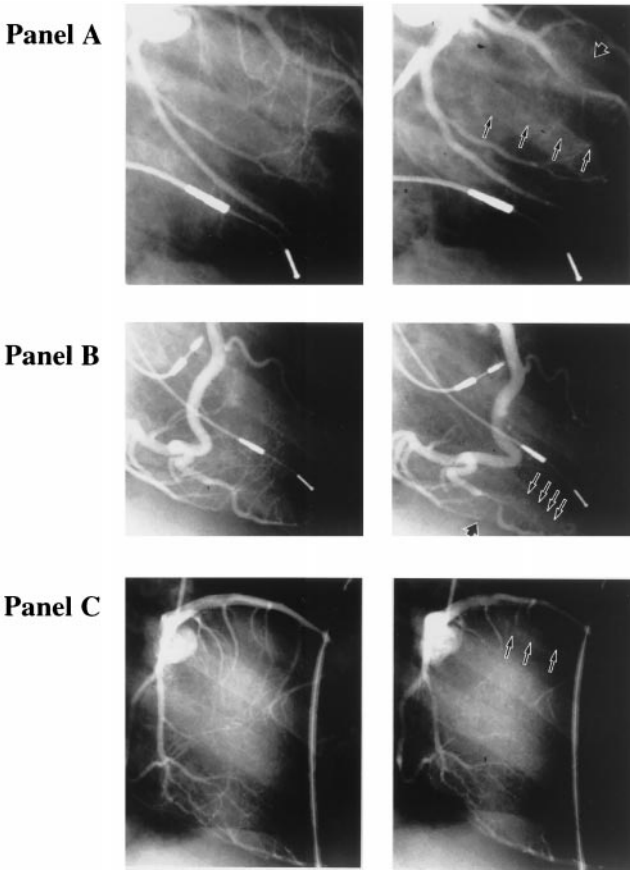

Figure 1. Figure illustrating coronary angiograms in three children with hypertrophic cardiomyopathy. Diastolic frames are on the left and systolic frames on the right. **Panel A** = 6-year-old male with mid-left anterior descending artery (LAD) bridging and compression of its intramyocardial branches. **Panel B** = 13-year-old female with bridging of proximal posterior descending branch of the right coronary artery with complete compression of its septal branches. **Panel C** = Complete compression of septal branches of the LAD. This child had bridging of an obtuse marginal branch. Large arrows indicate sites of bridging of epicardial arteries and small arrows indicate compression of septal branches.

with bridging was 28 ± 8 mm compared with 19 ± 8 mm in children without bridging, $p < 0.001$. Furthermore, children with bridging had a greater degree of asymmetrical septal hypertrophy and higher LV outflow gradients (Table 2, Fig. 2). The diastolic LV cavity in children with bridging was 39 ± 7 mm in contrast to 43 ± 6 mm in children without bridging; $p < 0.05$.

HEMODYNAMIC VARIABLES. At cardiac catheterization, 15 (65%) of the 23 children with bridging had LV outflow obstruction at rest or following provocation compared with 13 (38%) of the 34 children without bridging, $p = 0.08$. Mean resting LV outflow gradient was greater in patients with bridging than without (37 ± 34 mm Hg vs. 14 ± 24 mm Hg, $p = 0.005$). The association between LV outflow obstruction and bridging was further demonstrated by significantly higher LV systolic pressure in affected children (Table 2, Fig. 2).

EXERCISE THALLIUM SCINTIGRAPHY. Reversible myocardial abnormalities were present in 31 (65%) of 48 children

Table 2. Clinical Findings in HCM Children With or Without Myocardial Bridging (≥50% Max. Systolic Compression)

	All Children n = 57	Absent n = 34	Present n = 23	p Value
Age (yrs)				
At diagnosis (range)	10 ± 6	11 ± 6 (0.03–18)	10 ± 6 (0.1–17)	0.23
At angiography (range)	15 ± 4	15 ± 4 (6–20)	14 ± 4 (4–20)	0.35
Follow-up (yrs)				
From diagnosis	8 ± 6	9 ± 6	8 ± 6	0.7
From catheterization	4 ± 4	5 ± 4	3 ± 3	0.08
Gender				
Males	43 (75%)	28 (82%)	15 (65%)	0.25
Family history of HCM	25 (44%)	13 (38%)	12 (52%)	0.44
Family history of sudden death	12 (21%)	8 (24%)	4 (17%)	0.74
Clinical presentation				
Asymptomatic	10 (18%)	6 (18%)	4 (17%)	0.99
Chest pain	33 (58%)	20 (59%)	13 (57%)	0.92
Dyspnea	31 (54%)	18 (53%)	13 (57%)	0.99
Presyncope	29 (51%)	16 (47%)	13 (57%)	0.67
Syncope	23 (40%)	15 (44%)	8 (35%)	0.67
Cardiac arrest	4 (7%)	3 (9%)	1 (4%)	0.64
Echocardiographic indices				
Aorta (mm)	29 ± 4	29 ± 4	29 ± 4	0.87
Left atrium (mm)	39 ± 7	38 ± 7	39 ± 8	0.63
LVIDd (mm)	42 ± 7	43 ± 7	39 ± 6	0.02
LVIDs (mm)	23 ± 6	24 ± 6	21 ± 6	0.06
Interventricular septum (mm)	23 ± 9	19 ± 8	28 ± 8	0.0004
Posterior LV wall (mm)	11 ± 3	12 ± 4	11 ± 3	0.43
Septum to posterior LV wall ratio	2.2 ± 1.1	1.8 ± 0.9	2.7 ± 1.2	0.001
LV outflow gradient (mm Hg)	28 ± 35	16 ± 28	45 ± 37	0.002
Cardiac catheterization				
Right atrium (mm Hg)	6 ± 3	6 ± 3	5 ± 3	0.88
Systolic right ventricle (mm Hg)	34 ± 10	33 ± 9	36 ± 11	0.23
Mean pulmonary artery (mm Hg)	18 ± 7	18 ± 7	18 ± 6	0.99
Cardiac index (l/min/m^2)	3.1 ± 0.7	3.0 ± 0.6	3.2 ± 0.8	0.30
PCWP (mm Hg)	12 ± 5	12 ± 5	12 ± 5	0.67
Systolic LV (mm Hg)	123 ± 28	116 ± 21	133 ± 34	0.03
LV end-diastolic pressure (mm Hg)	16 ± 8	16 ± 9	17 ± 8	0.77
Mean aortic pressure (mm Hg)	72 ± 12	75 ± 13	68 ± 10	0.04
LV outflow gradient (mm Hg)	23 ± 31	14 ± 24	37 ± 34	0.005
Number with septal compression (%)	37 (65%)	14 (41%)	23 (100%)	< 0.0001

LVIDd = diastolic LV internal dimension; LVIDs = systolic LV internal dimension; PCWP = pulmonary arterial capillary wedge pressure.

who underwent thallium studies (Table 3, Fig. 2). Abnormalities in myocardial thallium uptake were also significantly associated with increased LV wall thickness (septum, 26 ± 9 mm vs. 16 ± 3 mm, p = 0.0001; higher ratio of septum:posterior LV wall thickness, 2.4 ± 1.1 mm vs. 1.4 ± 0.5 mm, p < 0.005), and greater LV outflow gradients at cardiac catheterization (26 ± 33 mm Hg vs. 7 ± 12 mm Hg, p < 0.05). Multivariate analysis demonstrated that LV septal thickness and septal perforator compression, and not LV obstruction or bridging, were independent predictors of reversible myocardial thallium uptake abnormalities (Table 4). After adjustment for confounding factors, the study has a power of 90% at 5% significance level to detect an odds ratio of 3 for a bridging effect on thallium abnormalities.

Thallium myocardial abnormalities most frequently affected the septum and anterior segments, the LV wall segments supplied by the most frequently bridged vessel. However, segmental defects in thallium uptake are often unrelated to the coronary artery compressed. The pattern of abnormalities on thallium scintigraphy is no different between the 16 children with LAD compression and the 7 with bridging of another coronary. Furthermore, stress-induced apparent LV cavity dilation, suggesting subendocardial ischemia, is a finding that cannot easily be attributed to bridging and was present in more than a third of the children. Thus, the distribution of myocardial thallium defects indicates the importance of factors other than bridging in etiology of the myocardial ischemia.

EXERCISE TESTS. There were no significant differences in mean exercise durations, resting and peak systolic blood pressure in children with and without bridging (Table 3).

ELECTROCARDIOGRAPHIC VARIABLES. The mean QT and QTc intervals and QTc dispersion were not significantly different in children with and without bridging (Table 3).

Table 3. Clinical Findings in HCM Children With or Without Myocardial Bridging (≥50% Max. Systolic Compression)

		Intramyocardial Bridging		
	All Children	Absent	Present	p Value
Treadmill exercise test	(n = 52)	(n = 32)	(n = 20)	
Exercise duration (s)	511 ± 228	534 ± 254	474 ± 178	0.36
Baseline heart rate (beats/min)	83 ± 14	82 ± 15	84 ± 12	0.48
Peak heart rate (beats/min)	167 ± 35	167 ± 39	166 ± 28	0.93
Baseline systolic BP (mm Hg)	123 ± 20	129 ± 19	114 ± 19	0.007
Peak systolic BP (mm Hg)	149 ± 43	154 ± 45	142 ± 38	0.32
Abnormal exercise BP response	26 (50%)	16 (50%)	10 (50%)	0.77
Exercise thallium scintigraphy	(n = 48)	(n = 30)	(n = 22)	
Abnormal study	31 (65%)	14 (47%)	17 (94%)	0.002
Number of abnormal segments	86/288 (30%)	34/180 (19%)	52/108 (48%)	< 0.0001
Perfusion abnormality				
Anterior	25	11	14	0.01
Septum	21	6	15	0.003
Subendocardium*	18	7	11	0.01
Inferior	11	4	7	0.17
Apex	9	4	5	0.47
Lateral	2	2	0	0.50
12-lead ECG	(n = 53)	(n = 32)	(n = 21)	
QT interval (ms)	433 ± 59	438 ± 52	425 ± 67	0.26
QTc interval (ms)	475 ± 50	471 ± 56	482 ± 40	0.31
QTc dispersion (ms)	40 ± 27	38 ± 25	42 ± 30	0.59
Ventricular tachycardia				
On Holter	7/42 (17%)	3/23 (13%)	4/19 (21%)	0.68
Induced at EP study	5/36 (14%)	3/24 (13%)	2/12 (17%)	0.99

*Reversible apparent LV cavity dilation.
BP = sphygmomanometer cuff blood pressure; EP study = electrophysiologic study.

AMBULATORY HOLTER MONITORING AND ELECTROPHYSIOLOGIC STUDIES. Nonsustained VT was recorded in 17% of the children during ambulatory ECG monitoring. Sustained VT was also induced in 17% of the children. Differences in VT on Holter and VT induced at EP study in children with or without bridging were not statistically significant (Table 3).

Clinical outcomes. Cardiac events (sudden death [n = 2], cardiac arrest [n = 4]) occurred in two children with bridging and in four without. The cumulative survival rate at 20 years of age in both children with bridging was 85 ± 10% and without bridging 82 ± 8%, p = 0.9 (Fig. 3). In addition, LV systolic dysfunction occurred in three children without bridging and in one child following transmural myocardial infarction (none in children with bridging). One child in each group underwent cardiac transplantation for severe symptoms and exercise limitation.

Compression of septal branches of the LAD. Children with partial or complete compression of septal branches of the LAD had significantly greater LV wall thickness, asymmetrical septal hypertrophy, thallium perfusion defects and LV obstruction compared with children without compression (Table 5). Septal compression occurred in all of the 23 children with bridging but in only 14 of the 34 children without bridging, p < 0.001. QT intervals, VT on Holter or induced at EP study, and prognosis were not significantly different in children with or without compression of the septal branches.

DISCUSSION

Several mechanisms have been postulated to explain an increased incidence of sudden death in HCM. These include ventricular arrhythmias, an atrial arrhythmia causing severe hypotension because of associated LV dysfunction, bradyarrhythmias, LV outflow obstruction and myocardial ischemia (1,4).

MYOCARDIAL ISCHEMIA. More than half of patients with HCM have reversible myocardial perfusion abnormalities as demonstrated by exercise thallium or sestamibi studies, despite having large normal epicardial vessels with high flow velocity (1,3,4). The perfusion abnormalities are believed to represent regions of myocardial ischemia caused by one or more mechanisms (1–17).

PREVALENCE AND CLINICAL SIGNIFICANCE OF BRIDGING. Bridging is a common finding, seen in up to 10% of patients who undergo coronary angiography (21–24). It is observed in up to 40% of patients with chest pain and normal coronary arteries after administration of drugs such as nitroglycerin and isoproterenol (22). Muscle bridges are identified at autopsy or aortocoronary bypass surgery in 5% to 86% of cases (24–27). Bridging is more common in cardiac diseases that are associated with LV hypertrophy (23,27,28). Its angiographic prevalence in adult patients with HCM is about 30% to 80% (11,22). Compression of the intramyocardial septal arteries also occurs more fre-

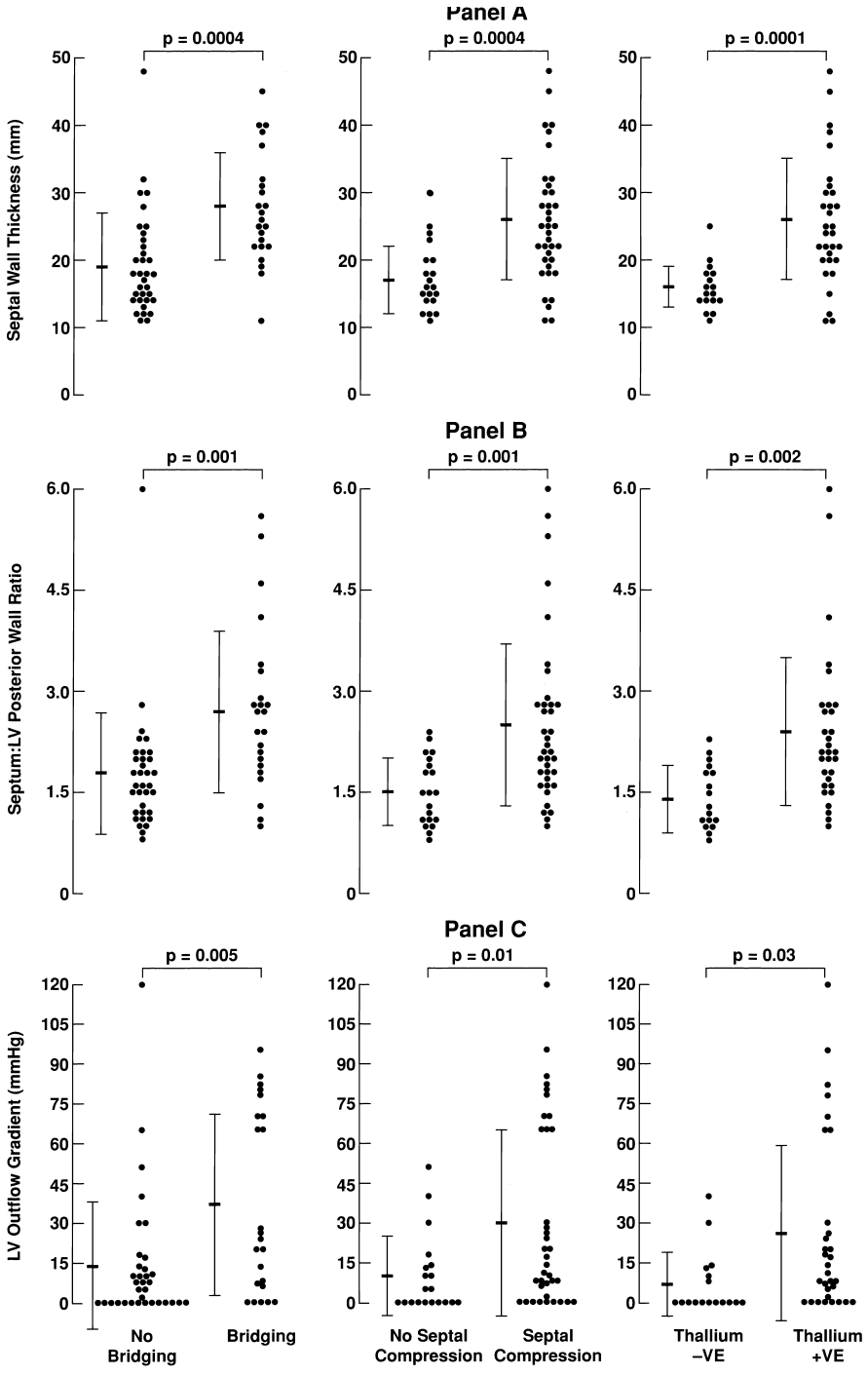

Figure 2. Figure showing interventricular septal wall thickness **(panel A)**, ratio of septum:posterior wall thickness **(panel B)**, and left ventricle outflow gradient at cardiac catheterization **(panel C)** in children with and without bridging of epicardial coronary arteries or compression of septal branches, and in children with and without myocardial perfusion abnormalities. Thallium (−ve), normal myocardial perfusion; thallium (+ve), abnormal myocardial perfusion.

quently in patients with LV hypertrophy. It is present in >70% of patients with aortic stenosis or HCM and may be related to severity of the LV hypertrophy (1,29).

Several reports have indicated that bridging may cause myocardial ischemia (13,24,25,28,30–32). Bridging has also been reported to cause myocardial infarction, abnormalities of the QT interval, VT and sudden death (13,33–37). Surgery to unroof or bypass the bridge and coronary artery stenting have also been described to improve symptoms in isolated cases and in small series of patients (13,38–41).

There is, however, as yet no convincing evidence that surgery improves morbidity or mortality in patients with bridging (24,27). Bridging may be an incidental finding in patients without another cardiac explanation for chest pain.

Table 4. Relation of Thallium Perfusion Abnormalities to Clinical Parameters: Logistic Regression Model for Predicting Thallium Perfusion Abnormalities

	Odds Ratio	p Value
Univariate analyses		
Interventricular septal wall thickness (per SD of 9 mm)	9.90	< 0.01
LV outflow obstruction (mm Hg)	1.02	< 0.01
Bridging (absent or present)	3.97	< 0.01
Septal perforator compression (absent or present)	7.30	< 0.01
Multivariate model with all 4 variables		
Interventricular septal wall thickness (per SD of 9 mm)	9.45	< 0.01
LV outflow obstruction (mm Hg)	1.01	0.2
Bridging (absent or present)	1.61	0.14
Septal perforator compression (absent or present)	3.05	< 0.05

SD = Standard deviation.

In several case reports myocardial hypertrophy was also present, and some of the patients in these reports may have had HCM. As only 15% of coronary flow occurs during systole, the physiologic relevance of bridging is questionable. Bridging may be postulated to cause myocardial ischemia if there is increased myocardial demand and/or diastolic compression of the coronary vessel. However, several studies have not demonstrated that bridging causes critical stenosis during diastole (17,22,30,31).

Yetman et al. (13) described a strong relation between bridging, chest pain, history of cardiac arrest, reduced exercise capacity, hypotensive responses to exercise, increased QTc dispersion, VT and poor prognosis in 36 children with HCM diagnosed and evaluated over about 40 years. They found no association between bridging and degree of LV hypertrophy or LV outflow obstruction. Following diagnosis with HCM, the five-year survival rate in children with bridging was 67% and 94% in the children without bridging. They concluded that bridging was an important cause of myocardial ischemia in their HCM children, and a direct determinant of clinical outcome. The

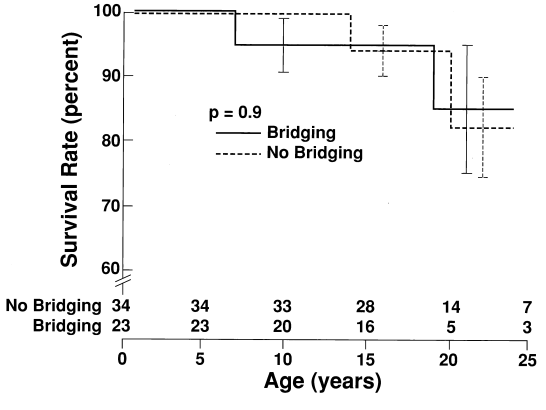

Figure 3. Figure showing survival rates in children with and without bridging. Cardiac death was defined as death or cardiac arrest. The number of children at different age intervals is indicated at the bottom of each panel.

Table 5. Clinical Findings in HCM Children With or Without Compression of Septal Branches of the LAD Artery

	Compression of Septal Branches		
	Absent	Present	p Value
Echocardiographic indices	(n = 20)	(n = 37)	
Interventricular septum (mm)	17 ± 5	26 ± 9	0.0004
Posterior LV wall (mm)	12 ± 4	11 ± 3	0.30
Septum:posterior wall thickness ratio	1.5 ± 0.5	2.5 ± 1.2	0.001
LV outflow gradient (mm Hg)	13 ± 29	35 ± 36	0.02
Cardiac catheterization	(n = 20)	(n = 37)	
Systolic aortic pressure (mm Hg)	108 ± 18	97 ± 12	0.01
Mean aortic pressure (mm Hg)	78 ± 13	69 ± 7	0.01
LV outflow gradient (mm Hg)	10 ± 15	30 ± 31	0.01
Coronary bridging	0/20	23/37 (76%)	< 0.0001
Exercise thallium scintigraphy	(n = 17)	(n = 31)	
Abnormal study	4 (24%)	27 (87%)	< 0.0001
Number of abnormal segments	9 (9%)	77 (41%)	< 0.0001

authors performed surgical unroofing of the myocardial bridge in three of the children and suggest that this procedure reduces myocardial ischemia. As thallium myocardial scintigraphy was available in less than a third of the children, the contribution of bridging to myocardial perfusion abnormalities was not adequately assessed.

The authors found coronary compression persisting through 50% of diastole, providing a credible mechanism for limitation of flow. Diastolic compression was calculated from the number of angiographic frames showing diastole and the proportion of these showing bridging (13). To allow this calculation, both the start and duration of diastole need to be accurately measured; this is difficult to do from angiographic records without simultaneous echocardiographic, electrocardiographic or phonocardiographic recordings. Coincidental quantitative coronary and diastolic information can be obtained from LV or aortic angiograms from the "nonselective" coronary runoff. This, however, may dramatically reduce sensitivity for the detection of moderate degrees of bridging. Using LV angiography may also result in detection sensitivities favoring detection of mid LAD compression, as this artery is seen more clearly than other epicardial arteries in right anterior oblique views and is seen at an orientation most likely to reveal eccentric compression.

Bridging is phasic, with transition from maximum to minimum compression. Identifying the end of the period of compression is therefore difficult and requires strict definition. Compression deforms the coronary lumen in an eccentric manner. The maximum compression is a measure of the short axis of an ellipse; lumen area is reduced according to elliptical and not circular geometry. For example, a concentric stenosis of 60% but an elliptical compression of 84% will reduce lumen area by 75% (27). Therefore,

regardless of the fraction of diastole during which compression persists, significant effects on flow will result only if compression remains severe.

Coronary compression increases with catecholamine administration (22). Therefore, coronary compression may be increased in frequency and severity during exercise when diastole is abbreviated. We assessed compression at rest and it is possible that during exercise the severity of compression may be flow limiting. Coronaries compressed at rest are likely to be those most severely affected during exercise. As the presence of bridging at rest does not predict myocardial perfusion abnormalities, it seems unlikely that the more frequently occurring bridging during exercise will do so. Furthermore, patterns of perfusion abnormality and artery affected were poorly matched.

Comparisons with similar studies. The present study was undertaken to investigate the prevalence of bridging and clinical significance of bridging and systolic compression of the septal branches of the LAD in children with HCM. We were unable to reproduce the findings of Yetman et al. (13). Bridging, despite identical definitions, was present more frequently, involved most epicardial arteries, and was occasionally at several coronary sites in the same child.

Exercise-induced reversible thallium myocardial perfusion abnormalities were more common in children with bridging and compression of septal branches. However, in contrast to the findings of Yetman et al. (13), bridging was associated with significantly greater LV hypertrophy, asymmetrical septal hypertrophy and LV outflow obstruction. Multiple regression analysis supported the hypothesis that the thallium abnormalities were related to severity of hypertrophy and presence of septal compression rather than caused by bridging. Symptoms, diminished exercise capacity, and abnormal blood pressure responses to exercise were not more common in children with bridging.

Yetman et al. (13) found that a QTc difference of >60 ms in any of the 12 ECG leads differentiated children with and without bridging with a sensitivity of 92% and a specificity of 77%. In our study, the QT, QTc, and dispersion of QTc intervals were not longer in the children with bridging. We were also unable to demonstrate a relation between bridging, spontaneous VT and VT induced at EP study, or cardiac events (sudden death, cardiac arrest, and myocardial infarction).

The differences between the findings of two studies may be explained in part by the fact that Yetman et al. (13) relied on echocardiographic and angiographic records extending over a period of 41 years from 1956 to 1997. Patient selection may have significantly influenced their findings; on average, in their group without bridging, HCM was diagnosed eight years earlier than in the group with bridging. The most rapid period of disease progression (LV hypertrophy and development of LV outflow obstruction) and highest incidence of sudden death is during the second decade of life. Calculation of survival rates from the time of diagnosis of HCM perpetuates the confounding effect of selection on the results. Indeed, symptoms, ventricular arrhythmias, cardiac arrest and sudden death are uncommon under 10 years of age. Hence, if the time interval from diagnosis of HCM is used to calculate survival, children aged 3.3 (median) years would be expected to have a better prognosis than those diagnosed at 11.2 years, irrespective of the presence or absence of factors such as bridging. In our study, children with and children without bridging were diagnosed and evaluated at similar ages, and we calculated age-related outcomes.

An important consequence of the long duration of the Yetman et al. (13) study is that the management of some of the children in that series predated the advent of beta-blocker and verapamil therapies, which are now used routinely to manage symptoms and myocardial ischemia in children with HCM. These children were severely affected with a high prevalence of risk factors for sudden death (Table 1). The better survival rates in our series may reflect more current methods of management.

Conclusions. Bridging was present in about half of our children with HCM. Mid-LAD was the most commonly affected vessel but other coronary arteries were also involved. Compression of septal branches of the LAD was present in 65% of the children. Both bridging of epicardial arteries and systolic compression of the septal branches were related to LV hypertrophy and LV outflow obstruction. Thallium myocardial perfusion abnormalities were related to LV hypertrophy, LV outflow obstruction, bridging and systolic compression of the septal perforators. Multivariate analysis identifies only LV hypertrophy and septal compression as independent predictors of thallium abnormalities. No significant association was found between bridging and symptoms, ventricular arrhythmias and incidence of sudden death. These findings suggest that cardiac surgery (or stenting) for bridged arteries in children with HCM is not indicated. Verapamil and beta-adrenergic receptor blockade therapy and relief of LV outflow obstruction may provide adequate anti-ischemic therapy.

Study limitations. The present study consists of a selected subset of children with HCM who were evaluated by cardiac catheterization and, in many cases, by EP studies in part because of severity of their clinical presentation. Our standard practice has been to assess the coronary circulation in all children undergoing catheterization to determine the gross coronary anatomy; in many children LV or aortic root angiography was considered to sufficiently visualize the proximal coronaries. A smaller proportion required selective coronary angiography for adequate characterization. Only this latter group has been considered for the current study, as nonselective studies do not have the coronary resolution required for evaluating the distal coronaries and for quantitative analysis. Nonetheless, the children studied are a subset of a population referred for tertiary evaluation and thus are not considered representative of the larger population of HCM children. It is likely, however, that our population of children more accurately reflects current

patterns of diagnosis and referral than that in the study of Yetman et al. (13). The prevalence of bridging in an unselected population of HCM children is expected to be lower in keeping with less severe cardiac hypertrophy. However, it is likely that the relation of bridging to severity of LV hypertrophy and myocardial perfusion abnormalities, and the finding that bridging does not significantly determine clinical outcome, may also apply to HCM children who attend nontertiary cardiac centers.

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